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CHROMATIC STROBE FLASH DISRUPTION
OF PURSUIT TRACKING PERFORMANCE

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and

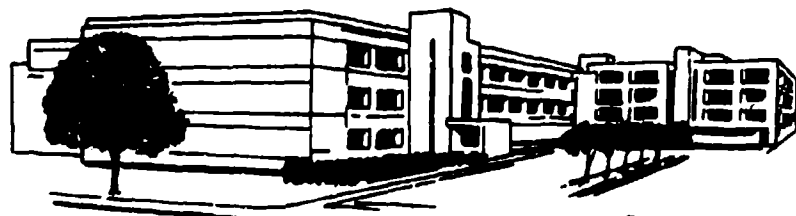
EDWIN S. BEATRICE, MD, COL MC

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Chromatic Strobe Flash Disruption of Pursuit Tracking Performance-
O'Mara et al

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Human Subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Reg 50-25 on the use of volunteers in research.

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ABSTRACT

Ten men used a viscous-damped mount optical tracking system during a study of the effects of strobe flashes and ambient lighting on pursuit tracking performance. The volunteers tracked a 0.5 mrad target moving to the left or right for 15 s at a constant angular velocity of 5.0 mrad/s. A single 170 μ s, 0.053 sr, 538 nm strobe flash was presented at random at the rate of one flash for each five trials. The flashes produced significant increases in the standard deviations of the horizontal and vertical aiming errors under both ambient light conditions. The average maximum aiming error was 0.6 mrad during bright ambient light trials. Approximately 2 s were required to return to normal control error rates. Flashes presented during the low ambient lighting conditions produced off-scale errors (>2 mrad). Recovery times averaged 6 s for a 1 mrad target and 3 s for a 4 mrad target. This study used large retinal area strobe flashes that were an order of magnitude below permissible safe exposure levels and much lower than levels produced by military laser devices. In spite of this limitation, single 538 nm flashes produced significant disruptions of pursuit tracking performance even though the behavior of the target was predictable. The magnitudes of these effects will be much greater for more intense single or multiple flashes and for targets which are engaged in unpredictable maneuvers. It cannot be concluded that smaller retinal area flashes will be equally effective in disrupting tracking performance. Future studies will investigate the effects of multiple small area flashes.

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INTRODUCTION

Soldiers engaged in visual tasks may be exposed to high intensity light which could disrupt the performance of those tasks. Short duration, wide spectrum photic stimulation may be produced by pyrotechnics, nuclear weapons, high-intensity search lights, and electronic strobes. Lasers represent a significant new light hazard in the combat environment. Directed laser light in the visible portion of the spectrum may produce flash blindness or retinal damage. Infrared high energy laser radiation may vaporize the surfaces of optical devices. The resulting reradiation from the optical surface will also produce flash effects. Frequency doubled neodymium yttrium-aluminum-garnet (YAG) lasers are being developed for use against optical systems (1). These lasers emit energy at 532 nm which is capable of causing flash blindness or injuring the operators of optical tracking systems.

The subject of flash blindness has been extensively investigated. Literature is available which describes the effects of high intensity flashes of light on the basic physiological and biochemical visual processes of laboratory animals and human volunteers. Psychophysical methods have been used to study the effects of visual stimulation on dark adaptation (2). Neurophysiological techniques have been used to investigate the effects of intense visual stimulation of the retina and visual pathways of the central nervous system (2). There are, however, serious limitations to the existing data base.

It is not possible to assess the total physiological and psychological effects of intense visual stimulation on the basis of studies of receptor physiology alone. The disruptive effects of startle, distraction, and stimulus related fluctuations in attention should also be considered. The consequences of photic stimulation will be task specific since modern weapons systems vary considerably with respect to the visual information processing demands placed on their operators. Operators may compensate for partial loss of vision or use task relevant information to operate over short periods of time without visual input. There is also relatively less information concerning the effects of monochromatic flashes (e.g., produced by lasers) and the effects of flashes occurring under bright ambient lighting conditions. Finally, the extrapolation of much of the flash effects literature to military utilization is not clear. The existing data do not provide specific guidelines for military field unit commanders who are concerned with the effects of visual incapacitation upon the operation of specific weapons systems under field conditions.

The purpose of this investigation was to study the effects of large retinal area, 538 nm (green) strobe flashes on pursuit tracking performance. During this study, operators of a viscous mounted optical system tracked constant velocity targets under low-light or bright-light viewing conditions. Single, randomly occurring, flashes appeared to originate from the target.

METHODS

Ten men participated in the study. The ages of the volunteers ranged from 18 to 40 years. Each volunteer was given an ophthalmological examination before the experiment. In accordance with the provisions of AR 40-46, each participant was tested with the Farnsworth 100 hue test and the Ishihara test for Color-Blindness (Kanchare Shuppan Co., Tokyo, Japan, 1969). Contrast sensitivity function and dark adaptation testing were also performed, and each volunteer received a slit lamp and funduscopic examination. All ten participants were judged to be within normal limits on these tests. The ophthalmological examination was also given after the study. Each participant was briefed on the purpose of the study and signed a volunteer consent statement before participating in the experiment.

Pursuit tracking performance data were collected under simulated field conditions (3). The simulator includes scale model targets and terrain and a full size bunker which houses a laser designator optical tracking device. The targets were track-mounted, scale model tanks driven on alternate trials to the left or right over a level course at a constant angular velocity of 5 mrad/s. Each trial started with the target stopped and the crosshairs of the designator sighting device aligned with a black bullseye at the center of a 0.5 mrad (traversing angle) square white aiming patch fixed to the side of the tank. On the command "ready — go" the target would traverse the terrain for approximately 15 s while the operator attempted to keep the crosshairs fixed on the aiming patch.

A television camera housed within the laser designator was used to monitor the relative positions of the target aiming point and the crosshairs of the sighting device. The video signal was processed on-line by a microprocessor which measured the horizontal and vertical axes errors at the rate of 25 samples/s. The resulting time series of errors were used to derive the mean errors, the standard deviations of aiming errors for the horizontal and vertical axes, and a percent time-on target (TOT) score (the cumulative time within a trial during which the crosshairs remained on the aiming patch). Summary statistics were made available immediately after each trial and the TOT scores were used to provide performance feedback to the designator operator. The summary statistics and the digitized time series were stored for subsequent analyses.

The strobe flash source in the BLASER designator was a Vivatar photoflash unit. The flash duration was $170 \mu\text{s}$ full-width, half-maximum (FWHM). The light emitting area was 3 cm^2 , and the distance to the eye of the observer was 7.5 cm. The solid angle subtended by the light source was therefore 0.053 sr.

A safety analysis of the source was made based on the TBMED-279 criteria for viewing of extended sources. It was assumed that all of the photoflash radiation was in the visible portion of the spectrum.

This was a conservative assumption because in fact much of the radiation was in the infrared spectral region which is less hazardous to the eye. It was further assumed that the provisions of TBMED-279, derived specifically for laser sources, were valid when applied to broadband light sources. For extended source viewing of visible light, TBMED-279 gives the equation:

$$MPE = 10t^{1/3} \text{ J/cm}^2 \text{ sr}$$

where MPE is the maximum permissible exposure, and t is the exposure duration in seconds. For a flash duration of 170 μ s, the MPE is 0.55 $\text{J/cm}^2 \text{ sr}$. For comparison, the unattenuated brightness of the Vivatar photoflash was measured. Then a green Wratten filter (No. 58, peak wavelength 538 nm, bandpass 57 nm, 54% peak transmission) was placed over the photoflash and the brightness was measured again. The brightness of the unattenuated source was 0.07 $\text{J/cm}^2 \text{ sr}$. The brightness was reduced to 0.037 $\text{J/cm}^2 \text{ sr}$ with the green filter. In both cases the ocular exposure was well below the MPE for these exposure conditions.

The dim and bright ambient light viewing conditions were controlled by introducing or removing a 2.5 OD neutral density filter within the optics of the designator. The terrain luminance was measured with a Spectra Minispot Photometer. The average luminance at the objective lens of the designator was 250 $\text{lm/m}^2 \text{ sr}$ with the filter removed. The average luminance was 0.8 $\text{lm/m}^2 \text{ sr}$ with the filter in place. No light from the terrain entered the bunker other than through the optics of the designator. An adjustable incandescent source illuminated the bunker. During the bright light condition the luminance inside the bunker was 5 $\text{lm/m}^2 \text{ sr}$. The bunker lights were turned off during the dim light tracking condition.

Each volunteer received training during three daily sessions before participation in the experimental (flash trial) sessions. Each training session consisted of 30 trials. Half the training trials were conducted under each of the two ambient lighting conditions. A 1 minute rest period was provided between successive trials and a 10 minute break was scheduled between the first and last 15 trials. An additional 10 minutes was allowed for partial dark adaptation prior to tracking under the dim light condition. This training schedule had been found to produce accurate and stable performance during a previous study (4). Two experimental sessions were then scheduled, these sessions were conducted in the mornings and during the same week. The test procedures were the same as those used during the training sessions. Half of the volunteers started with 15 dim light trials and half with 15 bright light trials on the first day. This order was reversed during the second session. One strobe flash occurred at random during each block of five trials. For the two sessions there was a total of six flashes presented under each of the two ambient lighting conditions.

The dependent variables were derived from the digitized records of the horizontal and vertical aiming errors. The middle 5 s of the

tracking data were used when deriving the standard deviation error scores for the non-flash (control) trials. This portion of the record was free from increased error rates associated with the start of target movement. For flash trials, the 5 s sample period was centered at the time at which the flash occurred and the 2.5 s pre- and post-flash segments were analyzed separately. The maximum horizontal and vertical errors (in mrad) following the flash were also recorded. Post-flash recovery of performance was evaluated in two ways. Recovery of "normal" performance was defined as the time required for the horizontal and vertical aiming errors to fall within a mean ± 2 standard deviation (95%) range based upon the operator's own control trial error data. The mean corresponded to the average control (non-flash) trials lead or lag error produced by the operator. Normal values were derived separately for the dim and bright light viewing conditions and for left and right target maneuvers. Recovery was also defined as the time required to reacquire targets of arbitrary dimensions (for example, the 0.5 mrad aiming patch or 1,2,3 and 4 mrad square targets).

Analyses of variance (ANOVA) were used to evaluate control and flash trial performance as a function of ambient lighting conditions, sessions, order of ambient lighting conditions within sessions, and order of flashes within sessions (effects of flash repetition). The ANOVA were performed using the BMD-P2V program for multifactorial mixed designs (5). The ANOVA were based upon a fixed effects model with repeated measures on all factors other than order of ambient lighting (a between group comparison). The Newman-Keuls test was used for post-hoc comparisons (6). The 0.05 significance level was used for all analyses.

RESULTS

Control performance. ANOVA of the control trial performance data showed significant increases in the standard deviations of horizontal (0.144 vs 0.079 mrad) and vertical (0.039 vs 0.028 mrad) tracking errors under the low ambient light viewing conditions. There were no significant within (trials) or between session changes in performance for these trials. The standard deviations of the horizontal errors were significantly greater when tracking to the right under both lighting conditions (bright: 0.079 vs 0.063 mrad, dim: 0.139 vs 0.127 mrad). The average horizontal error showed that the operators lagged the target by approximately 0.027 mrad when tracking in either direction. Analyses of the vertical errors showed significantly greater error standard deviations (0.028 vs 0.024 mrad) when tracking to the left and greater average aiming errors (-0.027 vs -0.013 mrad) when tracking to the right. The presence of these effects on errors required the "normal" tracking performance of each participant be defined separately for each direction of movement and ambient lighting condition. Estimates of the means and standard deviations of the tracking errors were obtained for each operator by combining appropriately categorized data from the control trials of both experimental sessions.

Flash effects. Examples of the effects of the strobe flash on

tracking performance of one participant are presented in Figures 1 and 2. The data in Figure 1 were obtained while the operator tracked the target to the right under bright light viewing conditions. The flash produced a 1.9 mrad horizontal deviation in the direction of the target's motion. There was no obvious effect on the vertical error during this trial. Figure 2 illustrates the effects of the same flash while the operator tracked the target to the right under conditions of low ambient illumination. This flash produced a downward deflection of the crosshairs and an off-scale horizontal error in the direction of target movement. Performance did not return to baseline levels until the end of the tracking trial. Note in Figure 2 that the large amplitude horizontal error caused a loss of data for both axes. This was a common (88%) occurrence following flashes during low ambient light trials. Loss of data occurred when large aiming errors caused the target to drift outside the analysis boundaries of the electronic error scoring system. It was not possible to measure precisely the amplitudes of the aiming errors during these trials.

There was agreement among participants concerning the subjective effects of the flashes. Under the bright light viewing condition the flash was described as a "brief" rectangular green flash. In general, participants did not report difficulties in tracking following the flash under the bright light viewing conditions. Under the low ambient lighting condition the initial rectangular flash was immediately followed by a brilliant full-field green image of "several seconds" duration. The initial flash effect was followed by a noticeable rectangular after-image. The effect usually persisted into the next tracking trial, i.e., for 1 to 2 minutes following the flash. The reports of all of the participants suggested that the flash was mildly aversive when presented under the low light condition.

The main effects of the flash on the standard deviations of the horizontal and vertical errors are summarized in Figure 3 and 4. The ANOVA showed that there were significant differences in error along both axes following flashes. Flash effects were significantly greater under the dim ambient light condition. There was a significant interaction between the effect of flash and ambient light on the horizontal error data (Fig 3).

The ANOVA also showed that there were significant between session flash effects on the standard deviations of horizontal error. The effects of repeated flashes (F1-F6) on horizontal error are illustrated in Figure 5. Detailed analyses of these data showed that the significant between sessions changes in flash effects were due to changes in error under the low light viewing condition. The last (F6) data point was significantly lower than the F4 value and all of the error observations from the first session and the F5 error was less than the F2 error value.

The average of the maximum horizontal errors following flashes was 0.611 mrad for the bright light condition. The greatest error was

obtained with the first flash presented during session one (mean, 0.844 mrad) and the smallest amplitude for the last flash during session two (mean, 0.44 mrad). However, this trend was not statistically significant between-sessions ($P = 0.372$) or between trials-within-sessions ($P = 0.141$). The 0.611 mrad error caused the crosshairs to drift outside the boundaries of the aiming patch but not outside the profile of the target vehicle. Vertical errors of greater than ± 2 S.D. magnitude were approximately equally distributed above and below the target aiming point. There were no clear trends in the directions of errors with respect to the direction of target motion under the bright light condition.

The frequent occurrence of off-scale errors under the low ambient light condition prohibited the accurate measurement of the maximum errors. The off-scale values corresponded to aiming errors completely outside the profile of the target vehicle. The typical horizontal errors were in the order of several vehicle lengths as determined by visually monitoring the television display in the control room. There was a tendency for the operators to lead the target after a flash under the low light condition (82.1% during session 1, 60.0% during session 2). There was no obvious trend in the direction of vertical errors following flashes.

The time required to recover "normal" performance was 2.16 s following flashes in the presence of bright ambient light. Under this condition, the average recovery time for the first flash was 2.53 s and 1.9 s for the sixth flash. ANOVA of the recovery times revealed no significant between-sessions ($P = 0.138$) or trials-within-sessions ($P = 0.113$) effects. However, a non-parametric (sign) test of the recovery times for the first vs last flashes was significant ($P = 0.01$). The average time required to reacquire a 1 mrad square target was 0.34 s under the bright light viewing condition. Recovery times based on larger targets were not evaluated for data collected during the bright light trials since errors were seldom greater than 1 mrad.

Recovery of "normal" performance following flashes presented during dim light trials could not be properly evaluated since stable baseline performance was usually not achieved during the post-flash epoch of the trial. It was possible to estimate recovery times by defining target zones of larger dimensions. The median recovery time for 1-4 mrad square targets for the first and second sessions are summarized in Figure 6. Each data point was derived by first determining the median recovery time for each operator during each session and then locating the medians of these values for all ten operators. The horizontal bars above and below the medians represent the range of the median values observed during both sessions. The data points of the upper boundary are equivocal since these observations were obtained from trials where recovery had not occurred at the end of the trial.

The ophthalmological examination was normal for all participants after the study.

DISCUSSION

Single 538 nm strobe flashes produced significant disruptions of pursuit tracking performance under bright and low light viewing conditions. The results indicated that the effects of the flash were different when presented against a low ambient light background. Under the low light condition the operators were partially dark adapted, i.e., the pupil was dilated and there was a concomitant increase in retinal sensitivity. The physiological response of the visual system to the strobe would be expected to be greater under these conditions. The time required to recover the low light level baseline adaptation level after a flash would also be greater. However, recovery of dark adaptation may not have been critical to the performance of the task in this experiment since the target was usually visible under low ambient illumination without a period of dark adaptation. The most important receptor event was more likely the immediate flash effect and associated short duration full-field green flare experienced by the operators. During this time the target was completely obscured. This period of receptor incapacitation was probably less than 1 s for bright ambient viewing and several seconds in duration during the low light viewing condition.

In this experiment, operators were trained to track targets moving at a constant angular velocity over a simple horizontal course. Under these conditions the behavior of the target was predictable and the operator should have been able to estimate the position of the target in the absence of visual input. This ability is known to be related to the complexity of target motion, training, the period of obscuration (7-11). In the present study, the longer duration of flash-blindness under the low ambient light condition should be associated with a greater cumulative error. After recovery of visual function, the time required to reacquire the target would be longer due to the greater final aiming error, and occasionally, due to the time required to locate the target when it was outside the field of view of the sighting device.

The results of this experiment suggest that the effects of flash may be basically different from those which would be obtained by simply masking the operators view of the target. There was a significant reduction in the effectiveness of the flash in disrupting performance with successive presentations. The type of stimulus, spacing of the flash trials, and the between-session reduction in flash effects do not support an explanation based on receptor physiology. The operators may have learned to estimate target position more accurately as they gained experience during the successive flash-blinded intervals. This type of improvement could also occur during simple masking of the visual field. The startling effects of the stimulus provide another explanation of the diminished effectiveness of the flashes with repetition. The initial startle effects of the unexpected, moderately intense, stimulus could be associated with inappropriate reflex muscular activity or disruption of the proprioceptive feedback mechanisms which are thought to be involved in estimating future target positions. Startle effects would be

expected to be greater for stimuli presented against a low ambient light background and would decrease with repeated flash presentation as observed during the present investigation.

CONCLUSIONS AND RECOMMENDATIONS

This study used large area (0.053 sr) strobe flashes that were an order of magnitude below permissible safe exposure levels and much farther below levels produced by military laser devices. In spite of this limitation, single 538 nm flashes produced significant disruptions of pursuit tracking performance even though the behavior of the target was predictable. The magnitudes of these effects will be much greater for more intense single or multiple large area flashes and for targets which are engaged in unpredictable maneuvers. It cannot be concluded that more intense, smaller retinal area, laser sources will be equally effective in disrupting tracking performance. Future studies will investigate this question.

The effects of multiple chromatic and white light flashes should be investigated. Smaller retinal spot sizes and different retinal locations should be studied. Optical countermeasures should be combined with evasive target maneuvers. The mechanisms and limitations of the operators adaptation to flashes should be investigated. The role of startle and environmental stress should be evaluated. The operator's response to optical countermeasures should be modeled and the results incorporated in existing parametric weapon system simulation models.

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LEGENDS OF FIGURES

- Figure 1 Flash effects on horizontal and vertical errors under bright light viewing conditions.
- Figure 2 Flash effects on horizontal and vertical errors under low light viewing conditions.
- Figure 3 Standard deviations of horizontal errors as a function of flash and ambient lighting conditions.
- Figure 4 Standard deviations of vertical errors as a function of flash and ambient lighting conditions.
- Figure 5 Standard deviations of horizontal errors following repeated flash exposures.
- Figure 6 Target reacquisition for 1-4 mrad target following flashes presented under low ambient light conditions.

APPENDIX

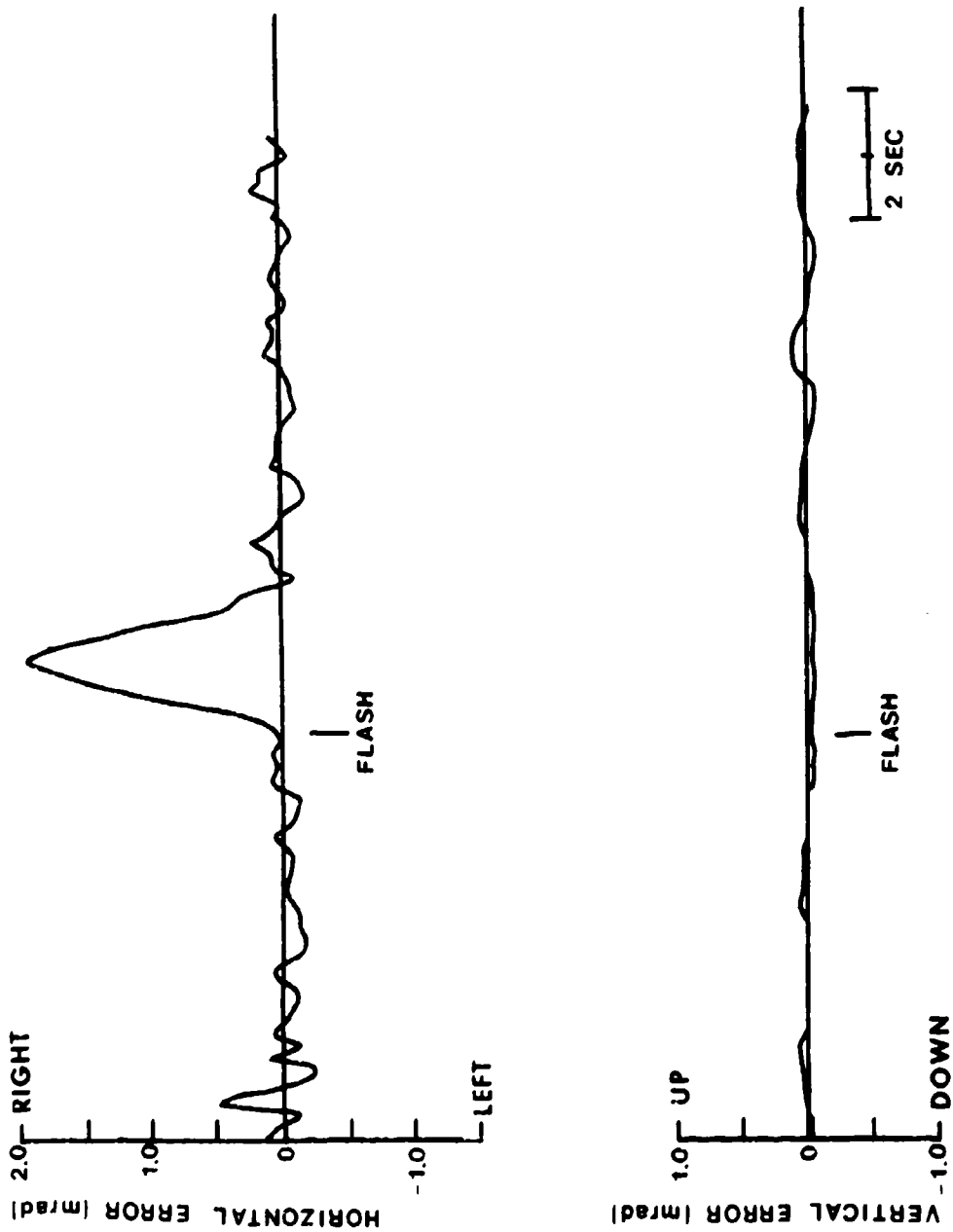


Figure 1. Flash effects on horizontal and vertical errors under bright light viewing conditions.

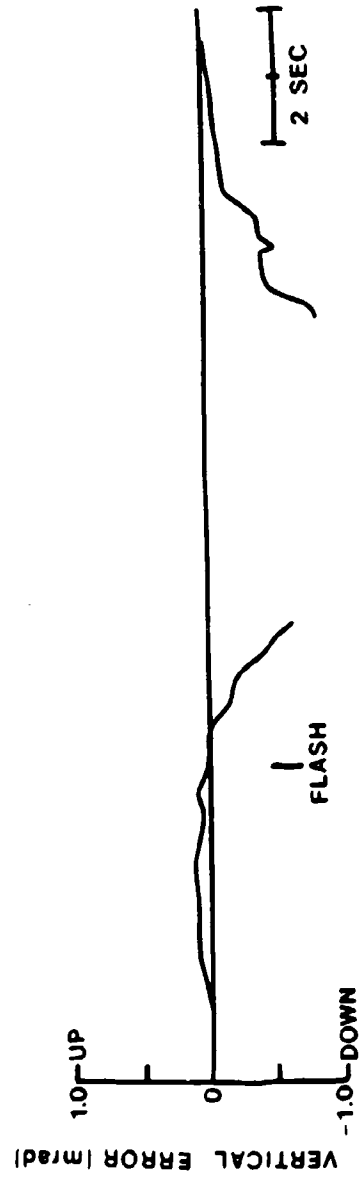
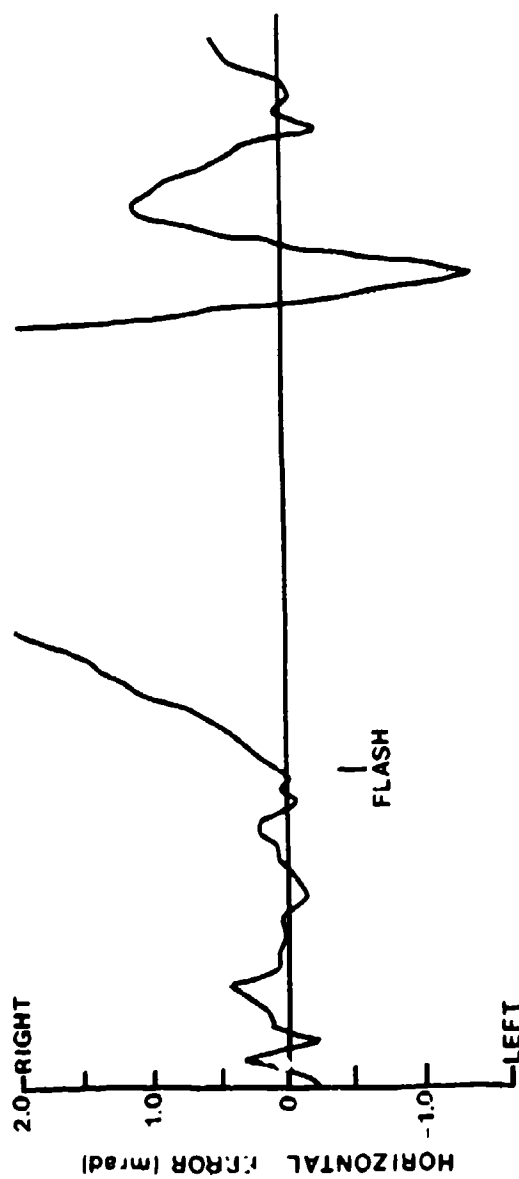


Figure 2. Flash effects on horizontal and vertical errors under low light viewing conditions.

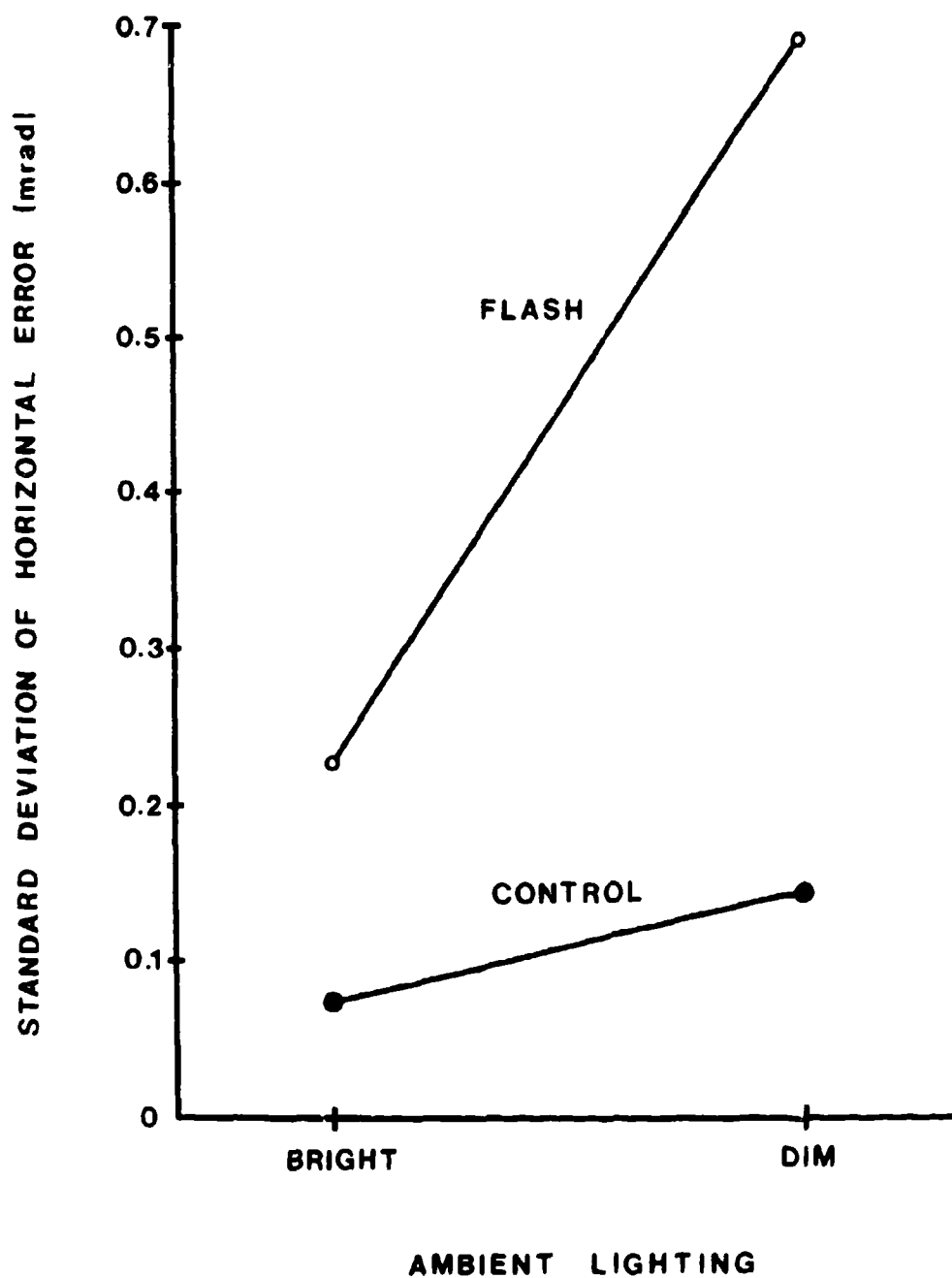


Figure 3. Standard deviations of horizontal errors as a function of flash and ambient lighting conditions.

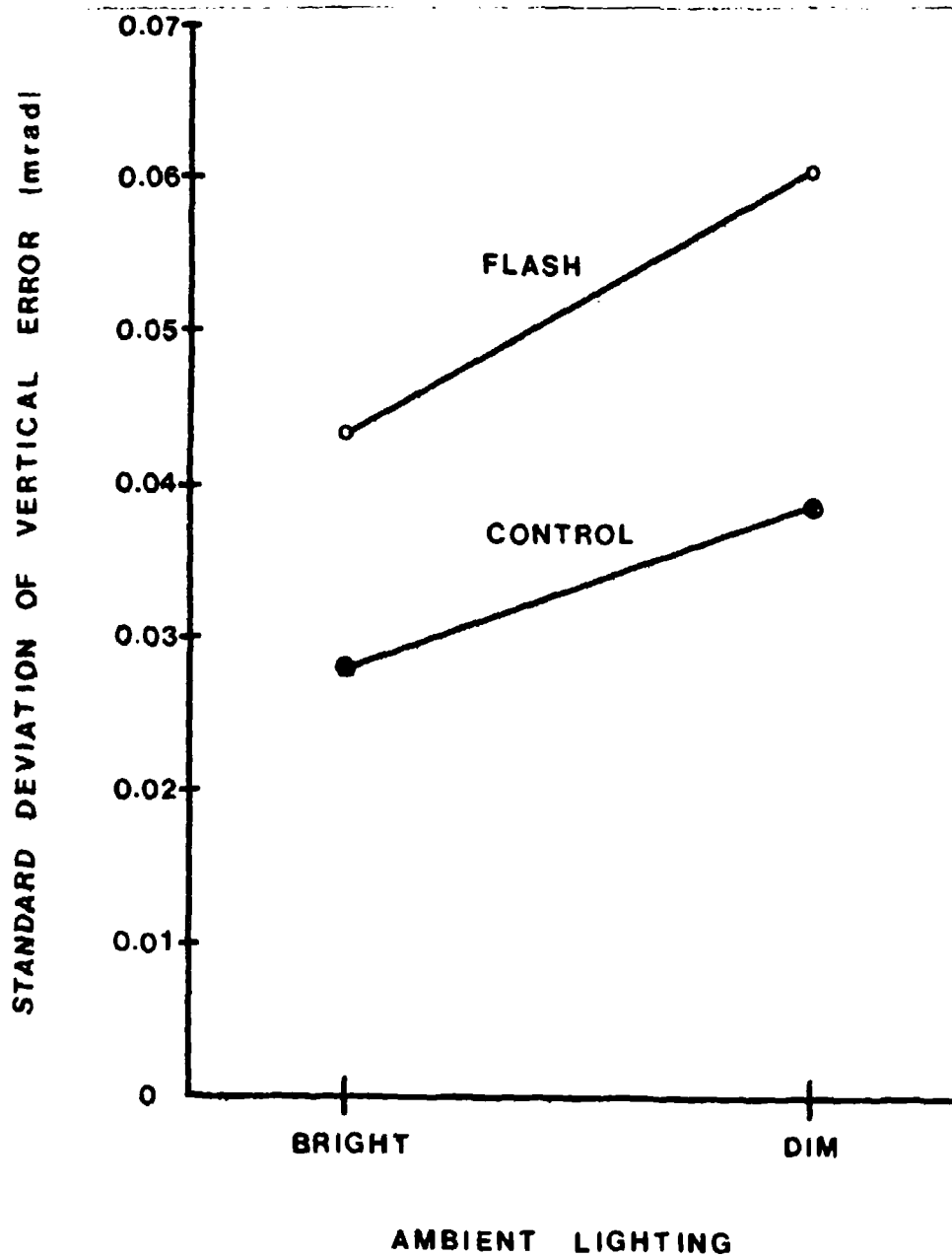


Figure 4. Standard deviations of vertical errors as a function of flash and ambient lighting conditions.

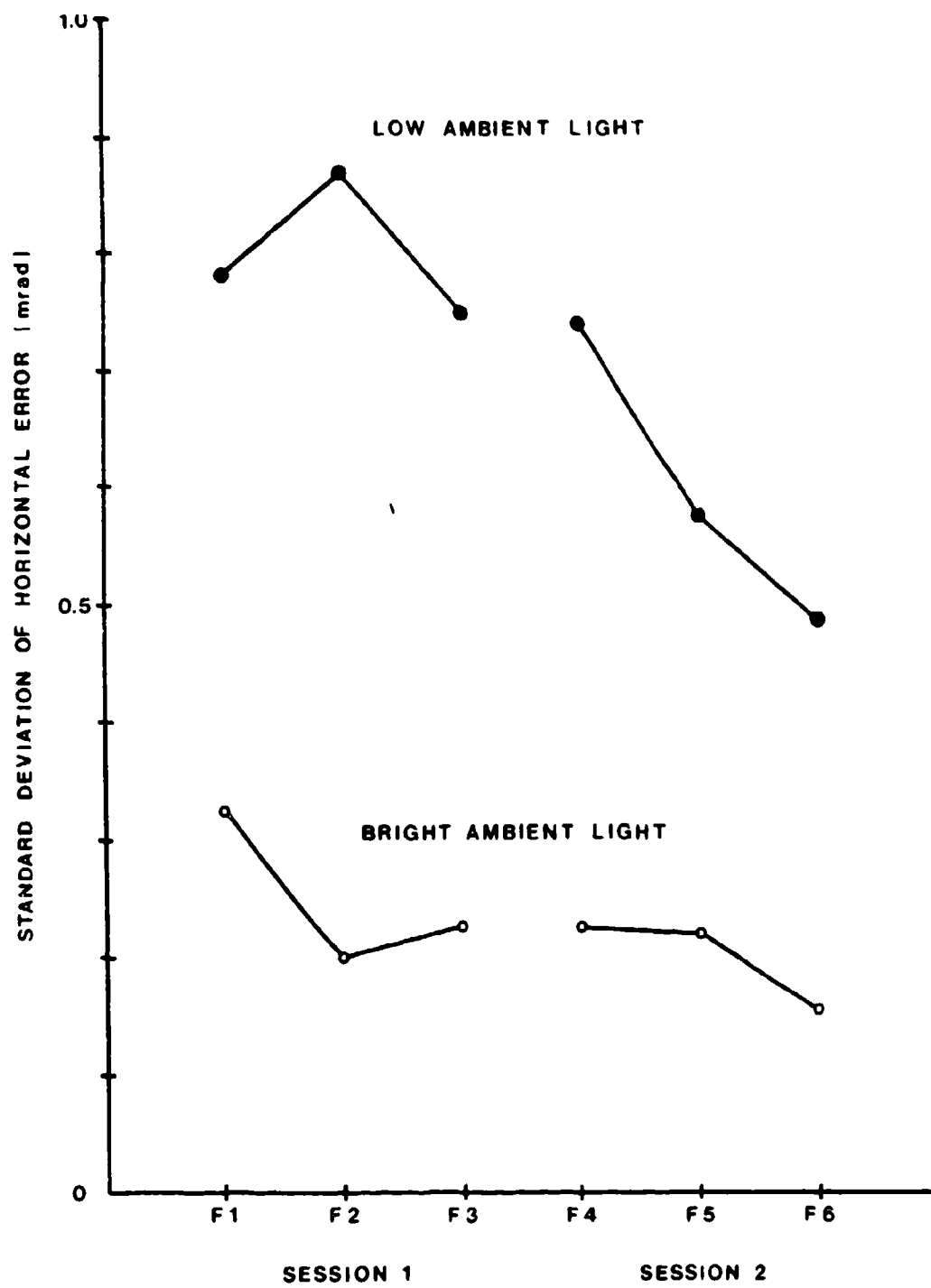


Figure 5. Standard deviations of horizontal errors following repeated flash exposures.

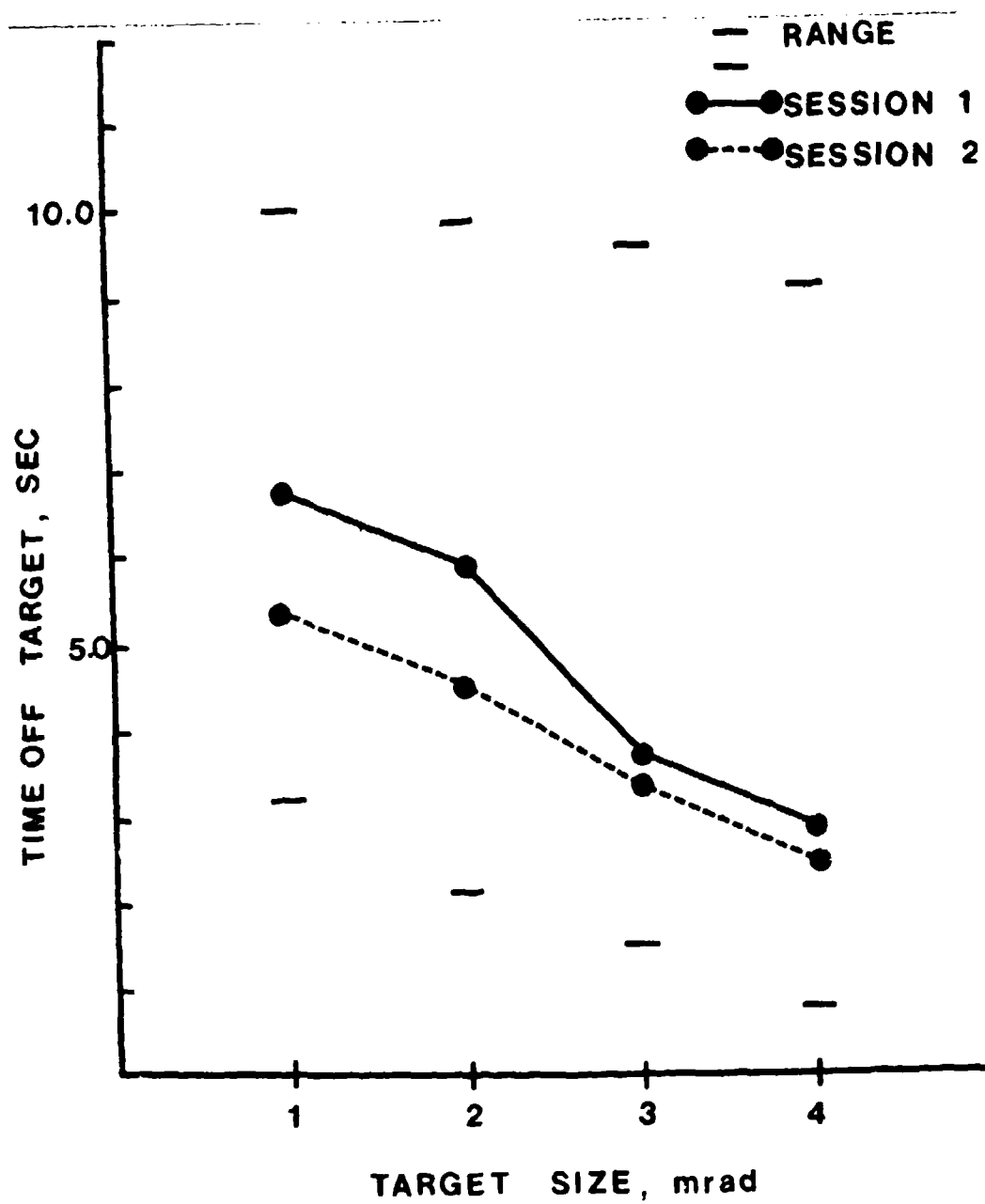


Figure 6. Target reacquisition for 1-4 mrad. target following flashes presented under low ambient light conditions.

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